# A Practical Approach for Modeling EUVL Mask Defects

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# EUVL Mask Defects

- Reflective mask - phase defects can be small.

  eg. A 55 nm diameter, λ/4 high "top-hat" defect is predicted to be printable for an ETS-like camera. This has the same volume as a 25 nm sphere.
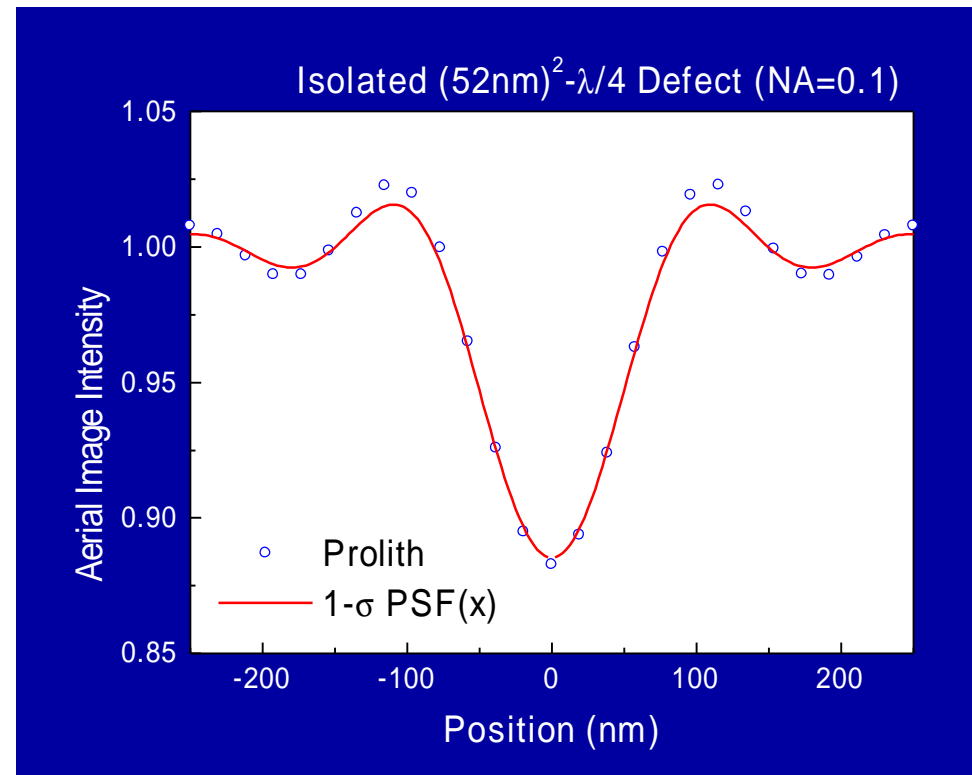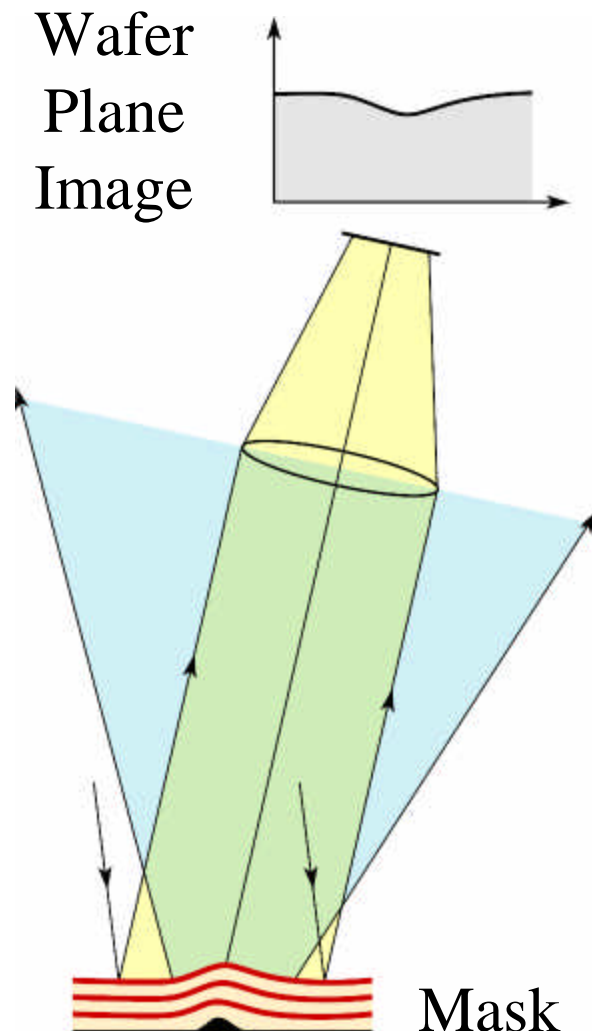- Multilayer coating can affect defect printability.

Questions:
- Where are we?
  - What is the critical defect size?
- Where are we going?
  - Produce a "*Defect free*" mask.
- How will we know when we get there?
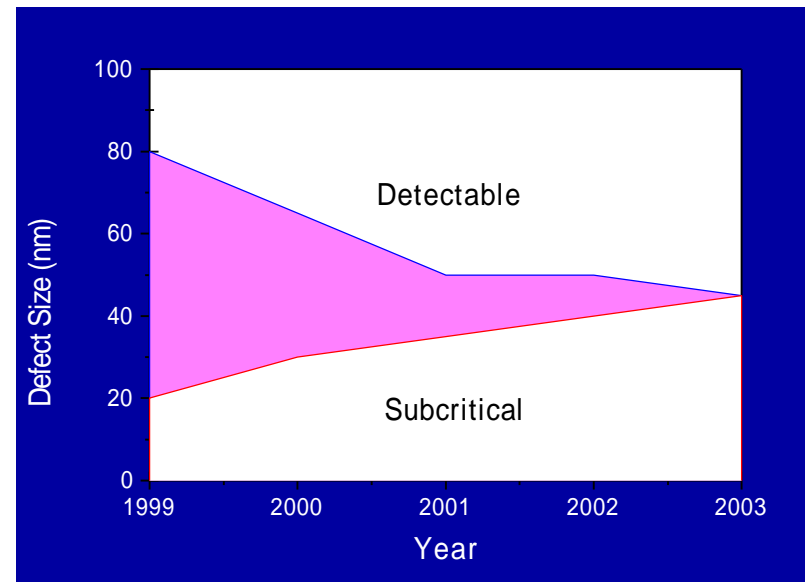


Answers require an understanding of defect printability.

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# An Unresolved Defect Will Scatter Light Out of the Entrance Pupil of the Camera

Wafer Plane Image

Mask

Isolated $(52nm)^2$-$\lambda$/4 Defect (NA=0.1)

Aerial Image Intensity

Position (nm)

- ○ Prolith
- — 1-$\sigma$ PSF(x)

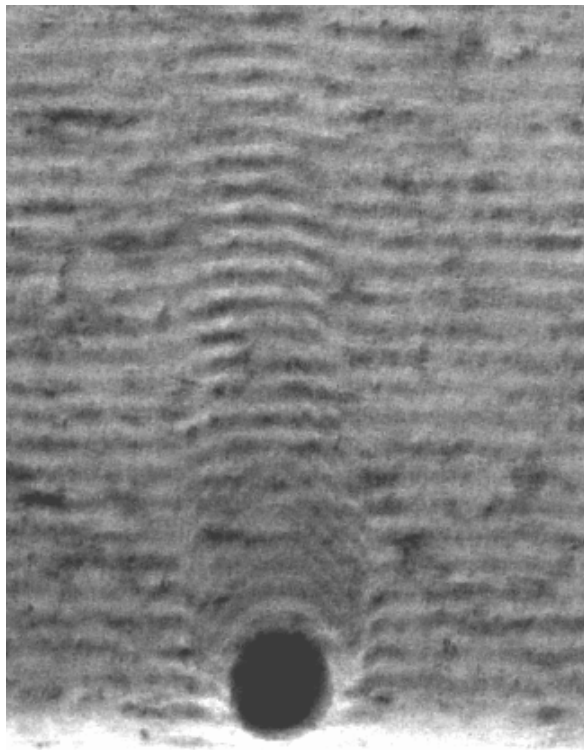For an unresolved defect the image intensity is proportional to the total *scattering cross section.*

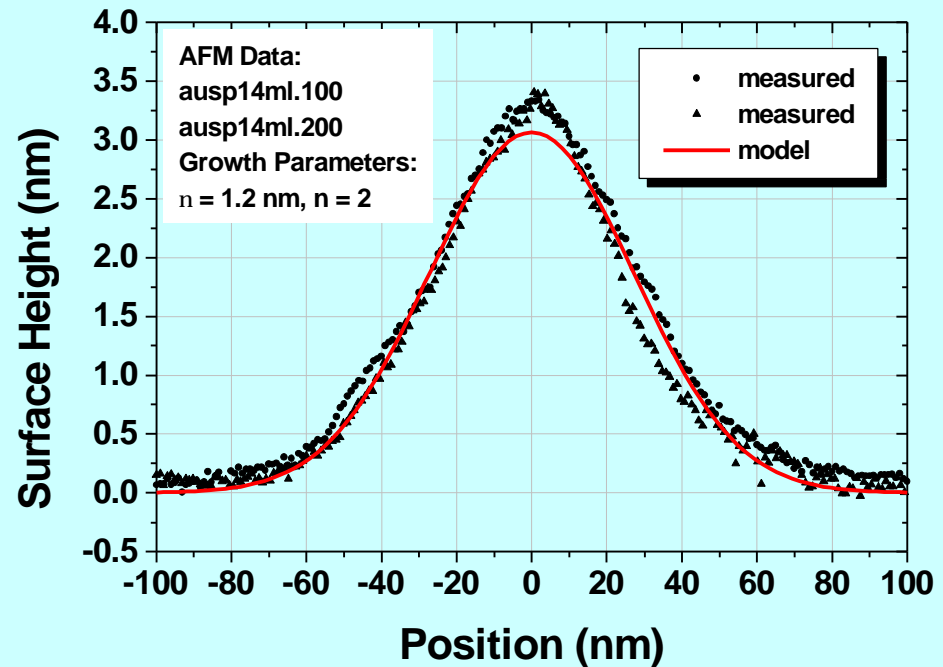$$I(r) = 1 - \mathbf{s} \cdot PSF(r)$$

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# Progress is Being made in Understanding the Multilayer Defect Structure

Experiments with Au nano-particles have spurred new developments in modeling. (see Mirkarimi *et al.*)
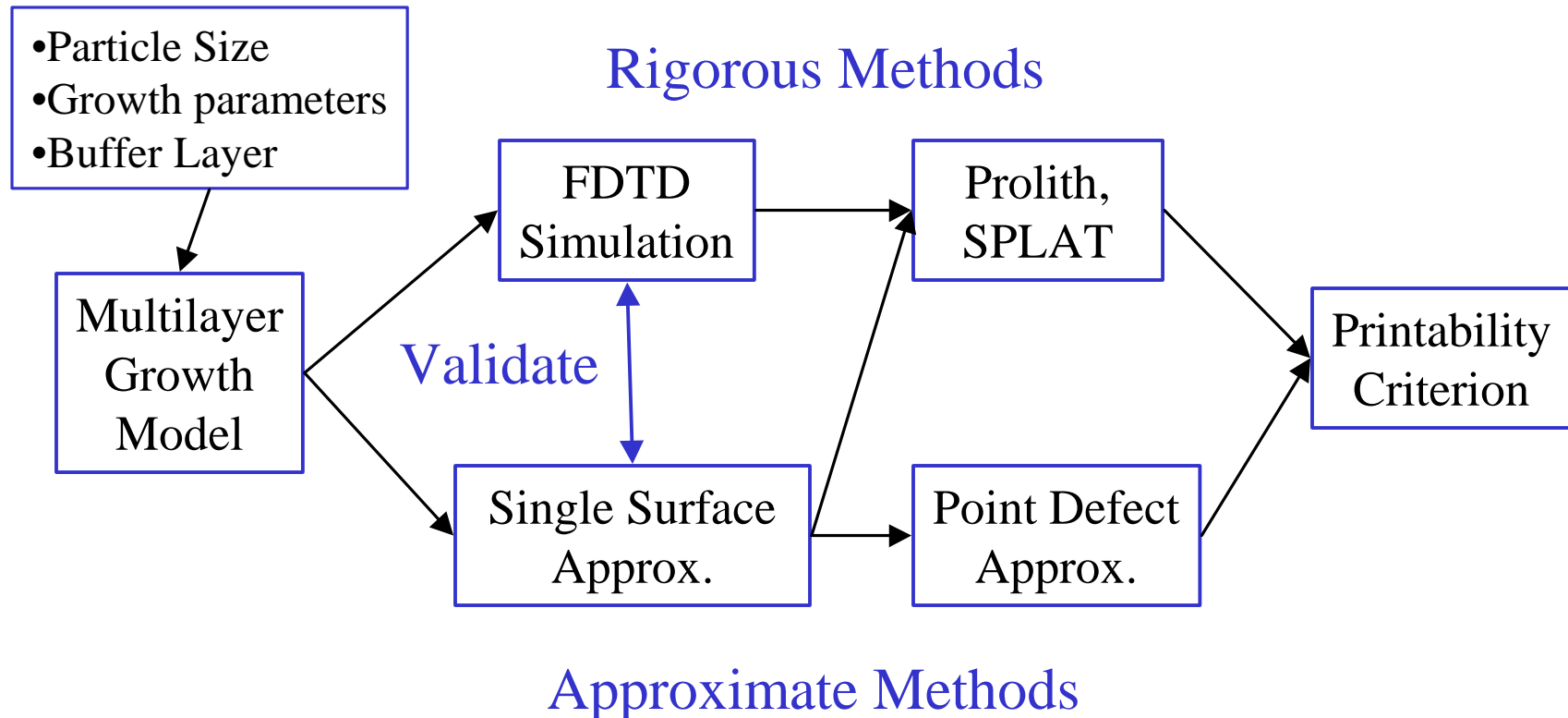
30 nm Au sphere

AFM of the multilayer top surface.

AFM Data:
ausp14ml.100
ausp14ml.200
Growth Parameters:
n = 1.2 nm, n = 2

- • measured
- ▲ measured
- — model

Surface Height (nm) vs Position (nm)

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# Defect Modeling: 4 Step Problem

Defect Structure     EM-Scattering     Imaging     Printability

•Particle Size
•Growth parameters
•Buffer Layer

Rigorous Methods

FDTD Simulation

Prolith, SPLAT

Multilayer Growth Model

Validate

Printability Criterion

Single Surface Approx.

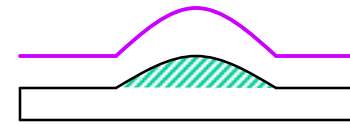Point Defect Approx.

Approximate Methods

Large parameter space requires the use of approximate methods.
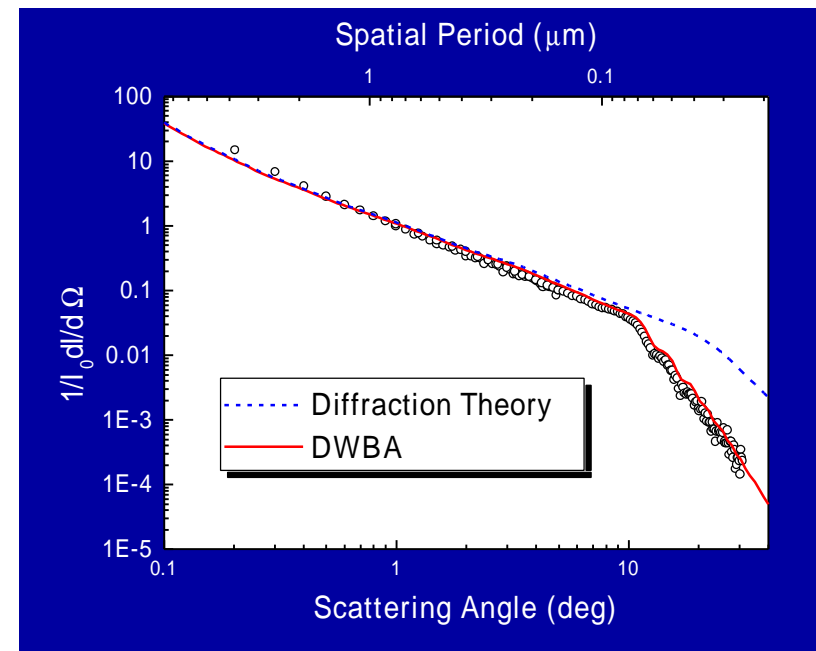
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# The Single Surface Approximation (SSA)

• Multilayer is replaced by a single reflecting surface.
• Simple scalar diffraction theory is used.
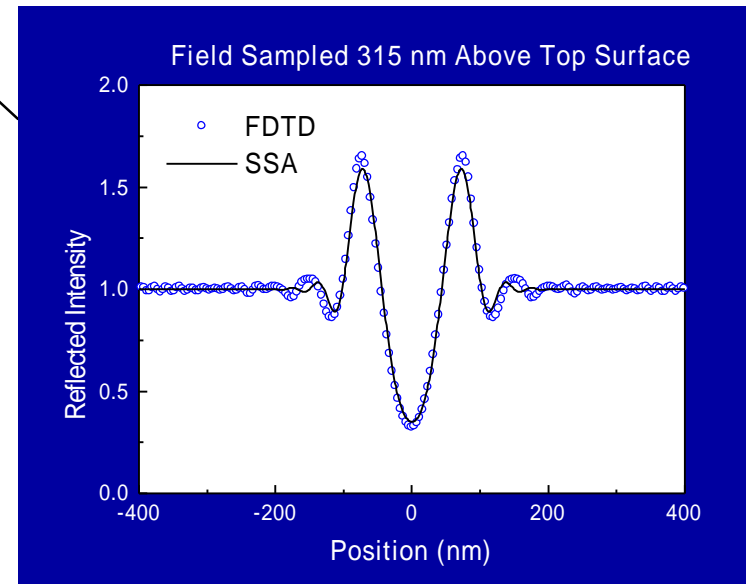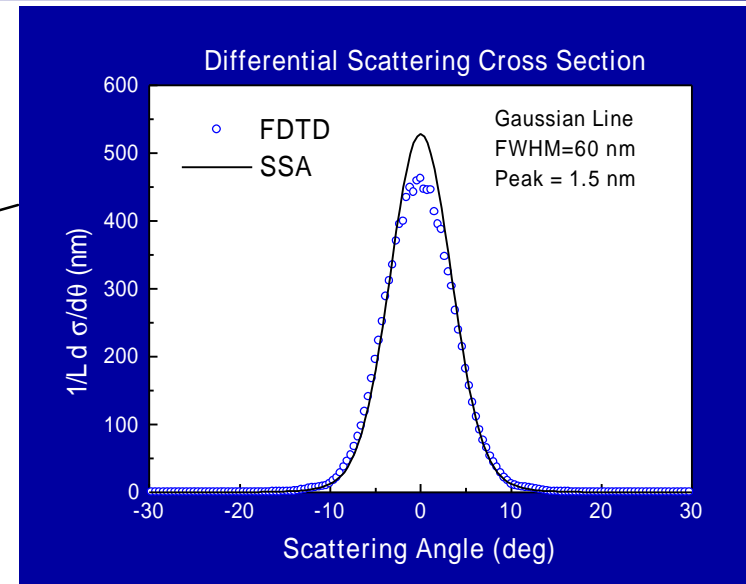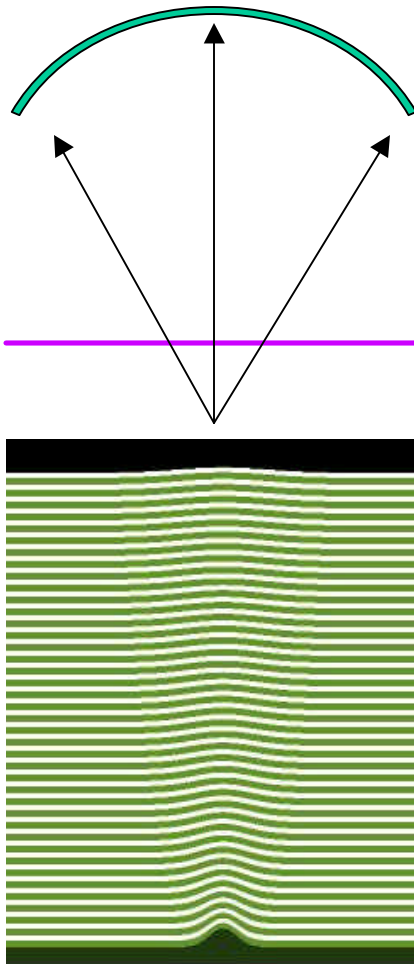
Phase Defect

$$f(\vec{x}) = 4ph(\vec{x})/l$$

• Intuition developed in studies of scattering from roughness.

• Breaks down for large scattering angles because of multilayer effects.

• The limits can be verified with the more rigorous FDTD calculations.
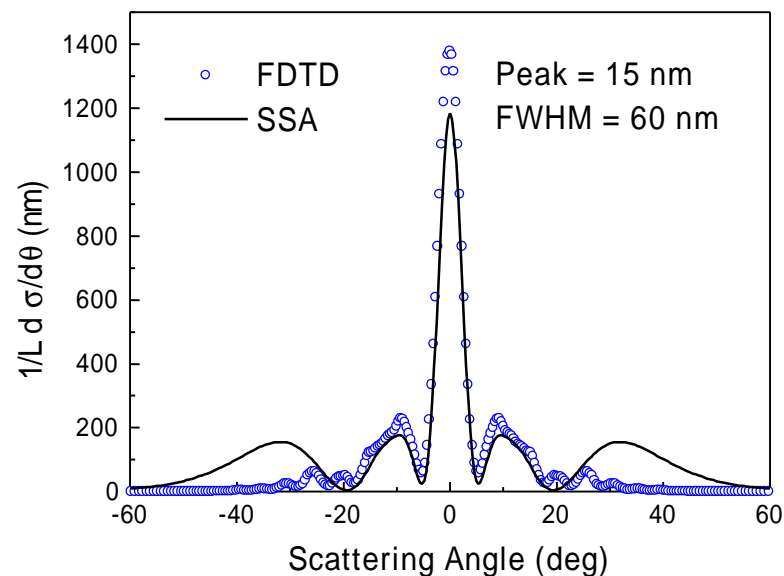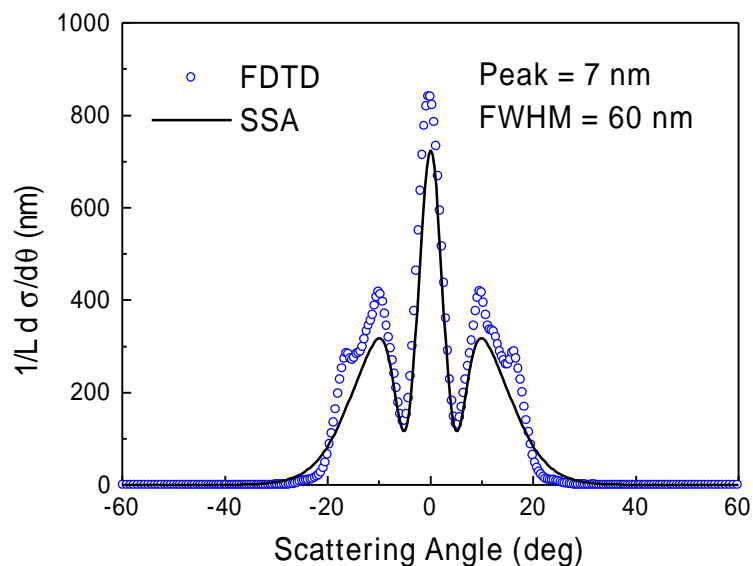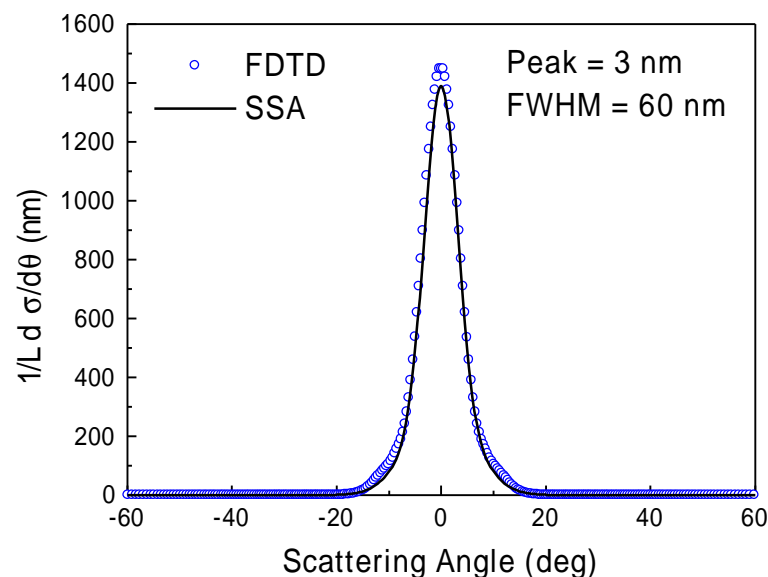


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# FDTD Simulations used to Check the SSA in both Near and Far Field

Far Field

Near Field



Differential Scattering Cross Section

○ FDTD
— SSA

Gaussian Line
FWHM=60 nm
Peak = 1.5 nm

1/L d σ/dθ (nm)

Scattering Angle (deg)

Field Sampled 315 nm Above Top Surface

○ FDTD
— SSA

Reflected Intensity

Position (nm)

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# Single Surface Approximation (SSA) Applies to Low Aspect Ratio Gaussian Bumps



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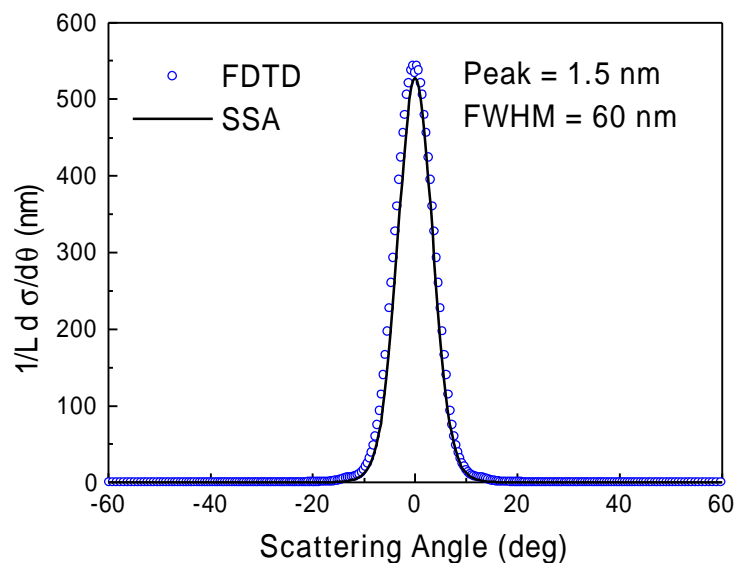
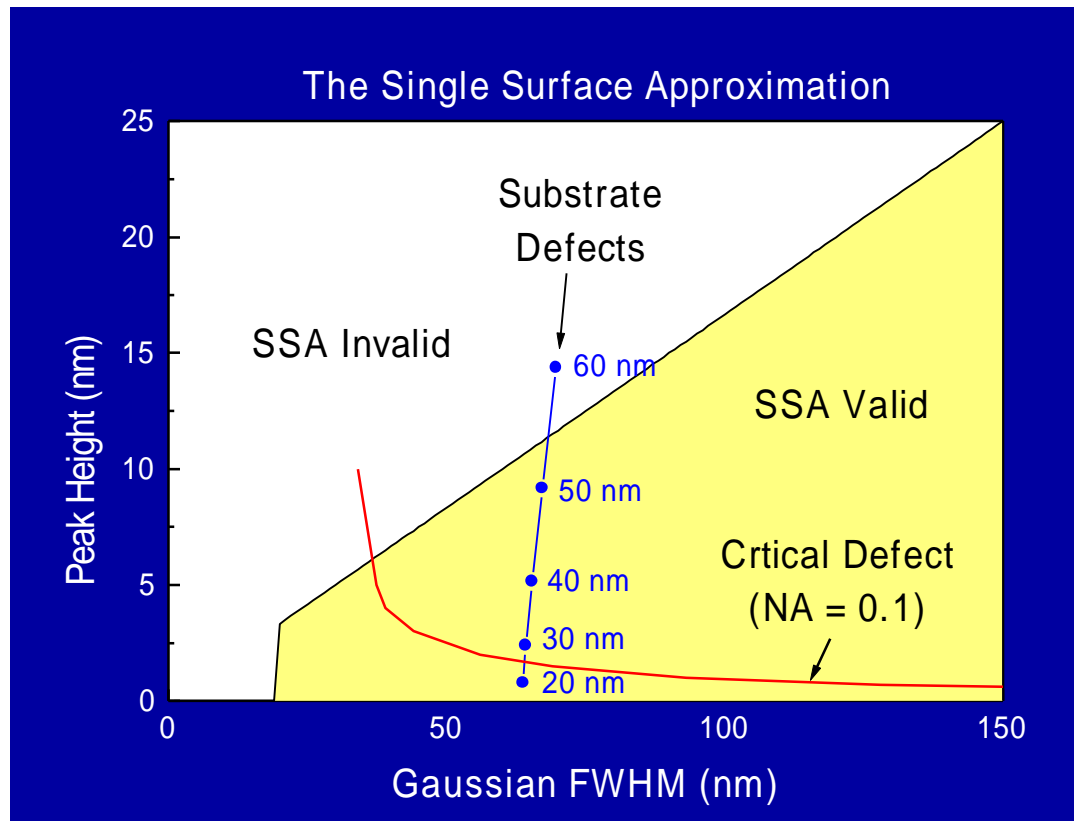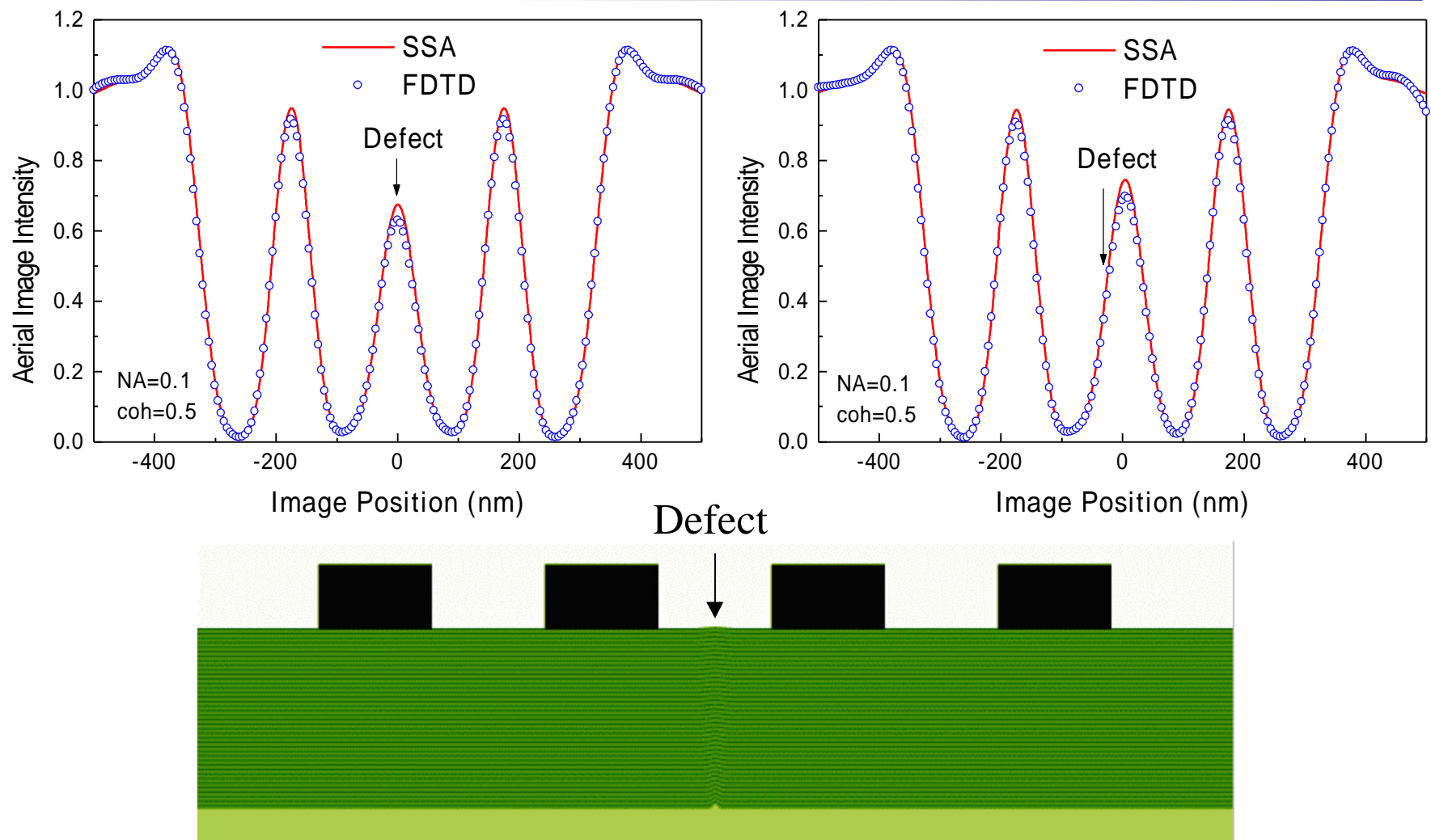# The Single Surface Approximation (SSA) is Applicable to the Critical Defects of Interest
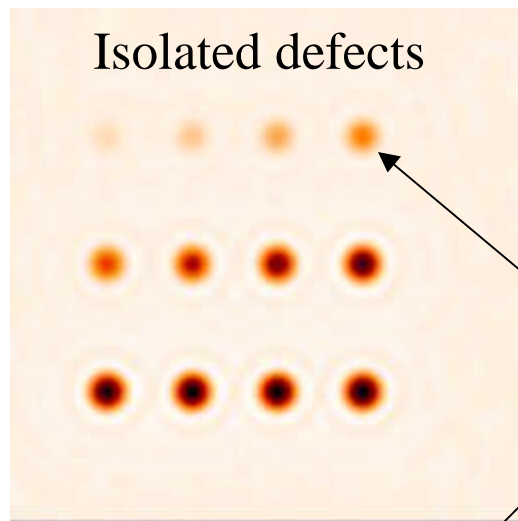


Substrate defect profiles are calculated using the non-linear growth model for the standard IBS Mo/Si multilayer.

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# SSA Tested for a Defect in Proximity to Absorber Lines



350 nm lines and spaces.  Defect FWHM=63 nm, peak height=1.8 nm.

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# *Printability Criterion*: More Than 5% Increase in Linewidth at the Extremes of Focal Range

Isolated defects

Aerial images calculated using the Single Surface Approximation.

Printable Defect

Gaussian Peak=1.5 nm, NA=0.1, 70nm 1:3

100 nm from Line Edge

0.5 μm

0.25 μm

In Focus

-0.25 μm

-0.5 μm

Linewidth Change (%)

FWHM (nm)
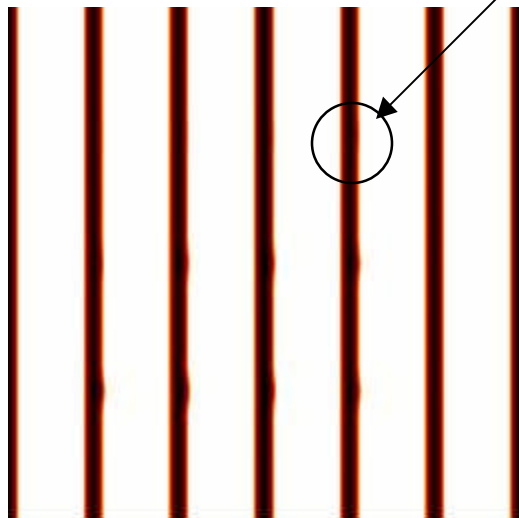
70 nm Lines/280 nm Pitch

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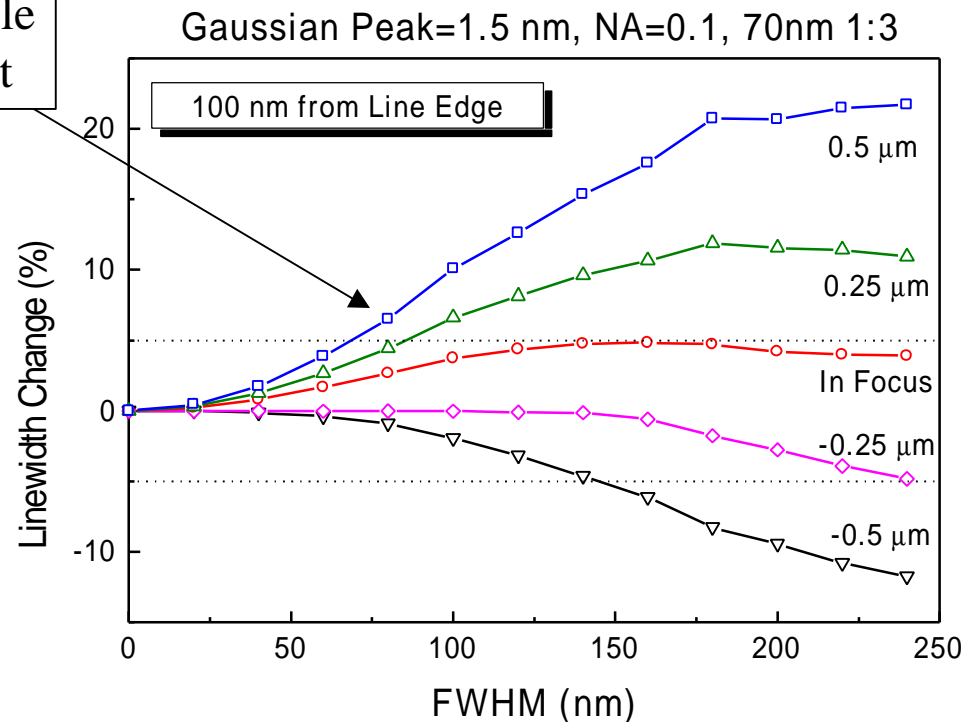
# Validation Experiments using EUV Scattering



Initial Measurements on 30 nm Spheres are in good agreement with the Single Surface Approximation.

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# Defect Printability is Related to the EUV Scattering Cross Section

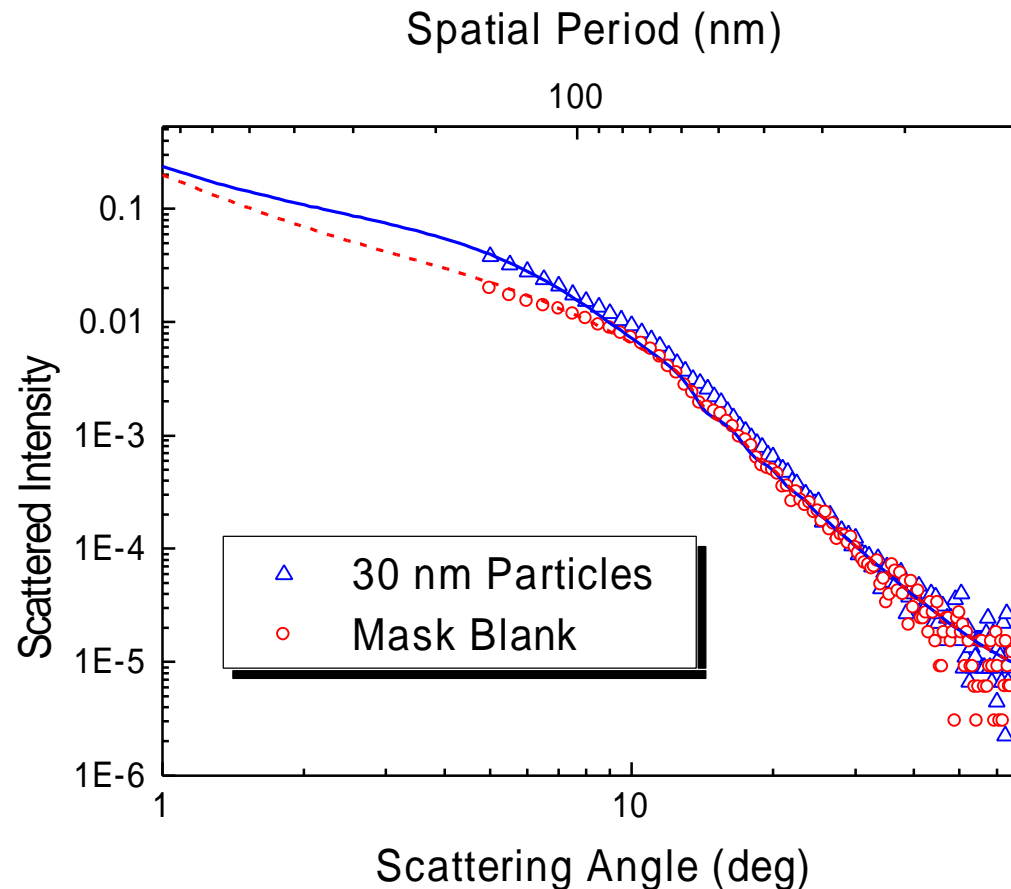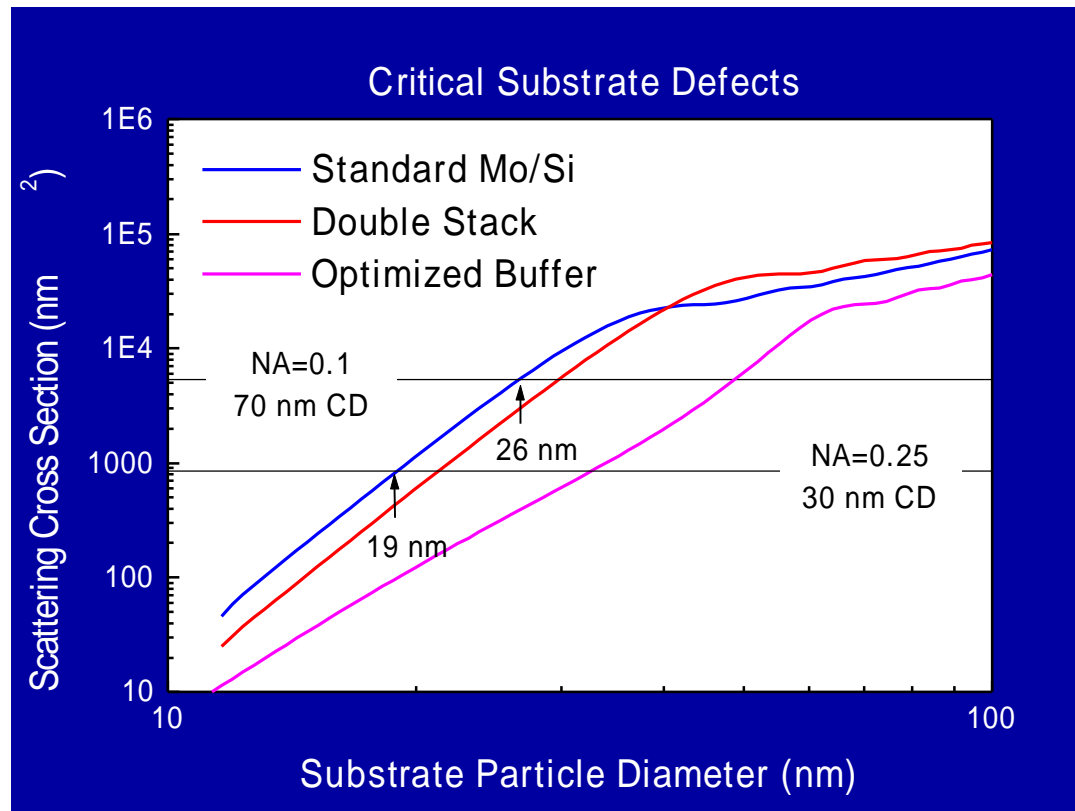The aerial image intensity is related to the total *scattering cross section*.

$$I(r) = 1 - s \cdot PSF(r)$$

The effect of multilayer smoothing may be modeled.

## Critical Substrate Defects

Scattering Cross Section (nm$^2$)

- Standard Mo/Si
- Double Stack
- Optimized Buffer

NA=0.1
70 nm CD

26 nm

19 nm

NA=0.25
30 nm CD

1E6
1E5
1E4
1000
100
10

10                                                              100

Substrate Particle Diameter (nm)

"Optimized Buffer" illustrates the potential gains by smoothing.

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# Summary

- The single surface approximation is shown to apply for EUVL critical defects.
- The point defect approximation provides an intuitive picture of the printability of unresolved defects.
- We are in a good position to determine the efficacy of smoothing strategies on the critical defect size.

| LineWidth | NA | Standard Mo/Si Diam. | "Optimized" Buffer Layer Diam. |
|---|---|---|---|
| 70 nm | 0.10 | 26 nm $\longrightarrow$ | 40 nm (?) |
| 30 nm | 0.25 | 19 nm $\longrightarrow$ | 30 nm (?) |

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